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(54) Magnetic random access memory with an elliptical junction

(57) The present invention concerns a magnetic tunnel junction (MTJ) -based magnetic random access memory (MRAM) cell (1) with a thermally assisted switching (TAS) writing procedure comprising a magnetic tunnel junction (2) formed from a ferromagnetic storage layer (21a) having a magnetization that is adjustable above a high temperature threshold, a reference layer (23) having a fixed magnetization, and an insulating layer (22) being disposed between the storage and reference layers (21 a, 23); **characterized in that** the junction (2) has an anisotropic shape, and wherein the ferromagnetic storage layer (21 a) has a magnetocrystalline anisotropy being oriented essentially perpendicular to the long axis of the anisotropic shape of the junction (2). The TAS MTJ-based MRAM cell of the present invention limits advantageously the effects of the junction shape anisotropy dispersion coming from the fabrication process and has a lower power consumption in comparison with conventional MTJ-based MRAM and TAS MTJ-based MRAM cells of the prior art.

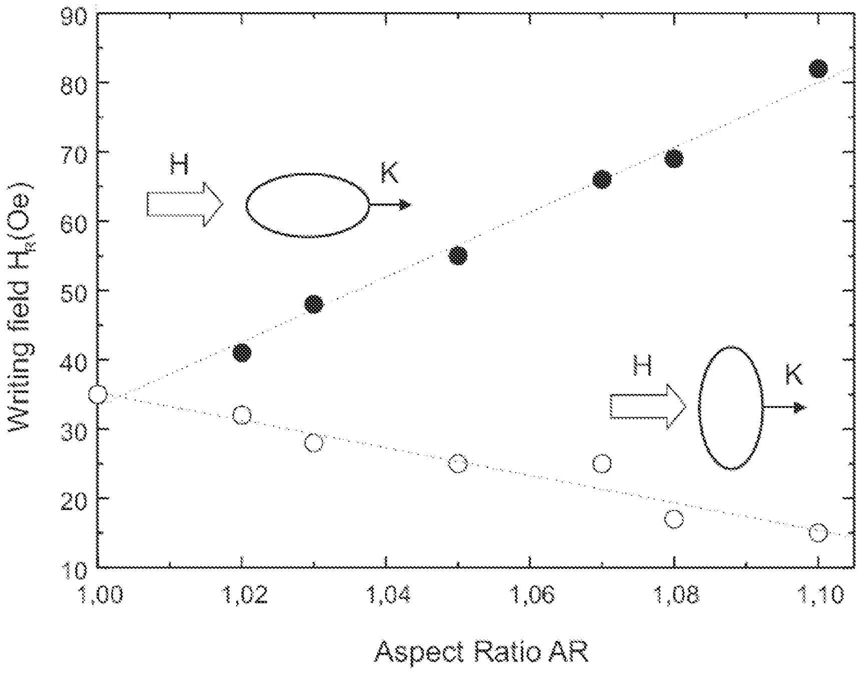

Fig. 5

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Description

Field of the invention

[0001] The present invention relates to the field of magnetic memories, especially non-volatile random-access magnetic memories used to store and read data in electronic systems. More particularly, it relates to Magnetic Random Access Memories, referred to as MRAM, based on magnetic tunnel junctions and an improvement of the shape of the memory cell used in a tunnel junction based MRAM using a thermally assisted write scheme.

Description of related art

[0002] Magnetic random access memories (MRAMs) have been the object of a renewed interest with the discovery of magnetic tunnel junctions (MTJ) having a strong magnetoresistance at ambient temperature. These MRAMs present many advantages such as speed (a few nanoseconds of duration of writing and reading), non volatility, and insensitivity to ionizing radiations. Consequently, they are increasingly replacing memory that uses more conventional technology based on the charge state of a capacitor (DRAM, SRAM, FLASH).

[0003] In conventional MTJ based MRAM, the memory cell consists of an element having a junction consisting of a stack of several alternatively magnetic and non-magnetic metallic layers. Examples of conventional MTJ-based MRAM devices are described in US-A-5640343. In their simplest forms, junctions of MTJ-based MRAM are made of two magnetic layers of different coercivity separated by an insulating thin layer where the first layer, the reference layer, is characterized by a fixed magnetization and the second layer, the storage layer, is characterized by a magnetization which direction can be changed. When the respective magnetizations of the reference layers and the storage layer are antiparallel, the resistance of the junction is high. On the other hand, when the respective magnetizations are parallel, the resistance becomes low.

[0004] Preferentially, the reference layer and the storage layer are made of 3d metals such as Fe, Co or Ni or their alloys. Eventually, boron can be added in the layer composition in order obtain an amorphous morphology and a flat interface. The insulating layer typically consists of alumina (Al_2O_3) or magnesium oxide (MgO). Preferentially, the reference layer can itself consist of several layers as described, for instance, in US-A-5583725 in order to form a synthetic antiferromagnetic layer. A double tunnel junction as described in the paper by Y. Saito et al., Journal of Magnetism and Magnetic Materials Vol.223 (2001), p. 293, can also be used. In this case, the storage layer is sandwiched between two thin insulating layers with two reference layers located on each opposite sides of the thin insulating layers.

[0005] Figure 1 shows a memory cell 1 of a conventional MTJ-based MRAM where a junction 2, comprising a storage layer 21, an insulating layer 22 and a reference layer 23, is placed between a selection CMOS transistor 3 and a word current line 4. A bit current line 5 is placed orthogonal with the word current line 4. When electrical currents flow in the word and bit current lines 4, 5, the word and bit magnetic fields 41 and 51 are respectively produced. Electrical currents are typically short current pulses from 2 to 5 nanoseconds having a magnitude on the order of 10 mA. An additional control current line 6 is intended to control the opening or the closing of the transistor 3 in order to address each memory cell individually.

[0006] During the writing process, the transistor 3 is in the blocked mode (OFF) and no current flows through the junction 2. The intensity of the current pulses and their synchronization are adjusted so that only the magnetization of the storage layer 21 located at the crossing of the two current lines can switch, under the combined effect of the word and bit magnetic fields 41 and 51.

[0007] During the reading process, the transistor 3 is in the saturated mode (ON) and a junction current will flows through the junction 2 allowing the measurement of the junction resistance of the memory cell 1. The state of the memory cell 1 is determined by comparing the measured resistance with the resistance of a reference memory cell. For example, a low junction resistance will be measured when the magnetization of the storage layer 21 is parallel to the magnetization of the reference layer 23 corresponding to a value of "0". Conversely, a magnetization of the storage layer 21, antiparallel to the magnetization of the reference layer 23, will yield a high junction resistance corresponding to a value of "1".

[0008] The basic structure of this type of conventional MTJ-based MRAM is described in details in US-A-4949039 and US-A-5159513 while US-A-5343422 is concerned with the implementation of a random-access memory (RAM) based on a MTJ based MRAM structure.

[0009] In order to ensure that this architecture is working properly during the writing process it is necessary to use memory cells with anisotropic form, with high aspect ratios, typically 1.5 or more. Such geometry is required in order to obtain bi-stable functioning of the memory cell; a good writing selectivity between the selected memory cell and the half-selected cells located on the same line / column; and good thermal/temporal stability of the information.

[0010] According to an improvement described in the document US-A-5959880, the aspect ratio of the memory cell can be reduced by increasing the magnetocrystalline anisotropy of the material that forms the storage layer. By doing this, the system is stable in time and temperature, and both states of the memory cell are well defined. On the other hand, the writing field required to reverse the magnetization of said memory cell from one stable state to another is significant and therefore the power consumed during the writing process is large. Conversely, if the magnetocrystalline anisotropy is low, the power consumed at writing is also low, but thermal and temporal stability of the storage layer are no more ensured. In other words, it is not possible to simultaneously ensure low power consumption and thermal and temporal stability.

[0011] Another improvement with respect to the above MTJ-based MRAM structure is the thermally assisted writing switching (TAS) process described in US2005002228. The particularity of the junction of such TAS MTJ based MRAM is that both the reference layer and the storage layer are exchange biased. More precisely, the reference and storage layers are pinned by interaction with an adjacent antiferromagnetic reference layer and antiferromagnetic storage layer respectively. During the thermally assisted writing process, a junction current pulse is sent through the junction rising the temperature of the junction and the magnetic coupling between the ferromagnetic storage layer and antiferromagnetic storage layer disappears. The junction is then cooled while a moderate magnetic field is applied by making a current to flow in the word current line, allowing for the reversal of the magnetization of the storage layer.

[0012] In contrast with the conventional MTJ-based MRAM, the TAS MTJ based MRAM structure is characterized by a considerably improved thermal stability of the storage layer due to the pinning of the antiferromagnetic storage layer. An improved writing selectivity is also achieved due to the selective heating of the memory cell to be written in comparison with the neighboring memory cells remaining at ambient temperature. The TAS MTJ-based MRAM structure also allows for a higher integration density without affecting its stability limit, and reduced power consumption during the writing process since the power required to heat the memory cell is less than the one needed to generate magnetization in the conventional MTJ-based MRAM structure.

[0013] A further improvement of the TAS MTJ-based MRAMs in terms of power consumption has been described in patent application US20060291276. Here, the writing field is further reduced by selecting a circular geometry of the memory cell junction. In this case, the writing field is only given by the magnetocrystalline anisotropy of the storage layer and there is no contribution from the shape anisotropy. However, the use of a circular geometry does not allow for simultaneously low power consumption and thermal and temporal stability of the storage layer.

[0014] The benefit of using a circular junction can be better understood by expressing the energy of the magnetic barrier height that has to be overcome in order to write the cell from a state "0", of low electrical resistance, to a state "1", of high electrical resistance. The barrier energy per volume unit, E_b, can be expressed as:

$$E_b = K + \frac{AR-1}{L} t M_s^2,$$

where the first term, K, is the magnetocrystalline anisotropy and the second term corresponds to the shape anisotropy. In the second term, AR is the aspect ratio of the junction, defined as the ratio of the length to the width L of the junction; t is the thickness of the storage layer; and M_s its saturation magnetization. The ellipticity can be defined as (AR-1), expressed in %.

[0015] The limitations of the prior art can be understood by considering that the barrier energy E_b increases with decreasing the size of the junction (L decreases and AR is constant), resulting in a significant increase in power consumption. In the other hand, the barrier energy E_b decreases with decreasing AR (L being constant), resulting in a loss of thermal and temporal stability.

[0016] In the case of a TAS MTJ-based MRAM with an exchange-biased storage layer, the storage layer stability at working temperatures is ensured by the pinning of the ferromagnetic storage layer with the antiferromagnetic layer, while, at writing temperatures, the pinning disappears and the memory cell can be written with a low writing field. In the case of a circular cell junction, a low writing field is obtained only by the low magnetocrystalline anisotropy. A low writing field and good thermal stability can then be obtained simultaneously by combining the junction geometry with the TAS MTJ-based MRAMs.

[0017] However, usual MRAM fabrication processes cannot guarantee perfectly circular junctions over a large array of memory cells, due to, for example, accuracy limitations in the pattering of the different junction layers. In addition, the magnitude of writing fields is strongly dependant on variations in the junction ellipticity. Figure 2 shows the dependence of the writing field H_R of the storage layer, on the aspect ratio of the junction for a conventional TAS MTJ-based MRAM cell. For example, the magnitude of the writing field more than doubles when the junction aspect ratio is increased from AR = 1.0 to 1.1, representing a 10 % variation typical from a usual fabrication process. The inset of figure 2 shows a top view of junctions with aspect ratio comprised between 1.0 and 1.1.

[0018] Such a variation of the aspect ratio results in a large dispersion of the writing field and a significant increase of the power consumption in a magnetic memory device containing an array of memory cells with circular junctions. In addition, electromigration effects in the current lines that occur for large electrical currents at high writing field may not be avoided.

Brief summary of the invention

[0019] An object of the invention is therefore to propose a new system and method which overcomes at least some limitations of the prior art.

[0020] Another object of the invention is to provide a magnetic tunnel junction (MTJ) -based magnetic random access memory (MRAM) cell with a thermally assisted switching (TAS) writing procedure, having a reduced dependence of the dispersion of the writing field on the junction aspect ratio due to the fabrication process.

[0021] According to the invention, these objectives are achieved by means of a system and method comprising the features of the independent claims, preferred embodiments being indicated in the dependent claims and in the description.

[0022] These objectives are also achieved by a TAS MTJ-based MRAM cell comprising a magnetic tunnel junction formed from a ferromagnetic storage layer having a magnetization that is adjustable above a high temperature threshold, a reference layer having a fixed magnetization, and an insulating layer being disposed between the storage and reference layers; said junction having an anisotropic shape, and said ferromagnetic storage layer having a magnetocrystalline anisotropy being oriented essentially perpendicular to the long axis of the anisotropic shape of the magnetic tunnel junction.

[0023] In an embodiment of the present invention, the anisotropic shape of the magnetic tunnel junction is an elliptical or a rectangle or a crescent or a semi-ellipse or a diamond shape.

[0024] In another embodiment of the present invention, the magnetic tunnel junction has an anisotropic shape with an aspect ratio comprised between 1.0 and 1.5.

[0025] In yet another embodiment of the present invention the magnetic tunnel junction has an anisotropic shape with an aspect ratio comprised between 1.0 and 1.1 or comprised between 1.0 and 1.05.

[0026] The present invention also encompasses a method of writing data in the TAS MTJ-based MRAM cell, the cell further comprising a select transistor being coupled with the magnetic tunnel junction and controllable via a word line, a connecting current line electrically connected to the magnetic tunnel junction, and a word current line; the method comprising the steps of:

heating the magnetic tunnel junction until it has reached a high temperature threshold;

aligning the magnetization of the ferromagnetic storage layer in a direction essentially parallel or antiparallel with the magnetization orientation of the reference layer;

cooling down the magnetic tunnel junction to a low temperature threshold at which the magnetization of the ferromagnetic storage layer is pinned.

[0027] In the context of the patent application, the expressions "ellipse", "elliptical", and "ellipticity" generally refer to any closed shapes having an anisotropic form such as ellipses, crescents, semi-ellipses, diamonds, rectangles, etc.

[0028] Advantages of the TAS MTJ-based MRAM cell of the present invention comprise limiting the effects of dispersion in the magnetic tunnel junction shape anisotropy coming from the fabrication process, a lower power consumption, and facilitated cell scaling down, compared with the MTJ-based MRAM and TAS MTJ-based MRAM cells of the prior art.

Brief Description of the Drawings

[0029] The invention will be better understood with the aid of the description of an embodiment given by way of example and illustrated by the figures, in which:

Fig. 1	shows a schematic view of a magnetic tunnel junction (MTJ)-based magnetic random access memory (MRAM) cell according to the prior art;
Fig. 2	shows the dependence of the writing field of the storage layer on the aspect ratio of the junction for a conventional TAS MTJ-based MRAM cell;
Fig. 3	represents a TAS MTJ-based MRAM cell comprising a magnetic tunnel junction according to an embodiment of the invention;
Fig.4	shows an exploded view on the exemplary magnetic tunnel junction of the TAS MTJ-based MRAM cell of Fig. 3;

Fig. 5	represents the variation of the writing field with the magnetic tunnel junction aspect ratio for a magnetocrystalline anisotropy axis of the ferromagnetic storage layer 21 a being parallel and perpendicular to the long axis of the of the junction;
Fig. 6	shows a top view of a conventional junction with an aspect ratio of 1.5, and two junctions according to an embodiment of the invention, with aspect ratios of 1.0 and 1.05 respectively.

Detailed Description of possible embodiments of the Invention

[0030] Figure 3 represents a thermally assisted switching (TAS) magnetic tunnel junction (MTJ) -based magnetic random access memory (MRAM) memory cell 1 according to an embodiment of the invention. The TAS MTJ-based MRAM cell 1 comprises a magnetic tunnel junction 2 placed between a selection CMOS select transistor 3 and a connecting current line 7 for passing a junction current pulse 31 flowing through the junction 2 when the transistor 3 is in the saturated or open mode (ON). A control current line 6 is used to control the opening and the closing of the transistor 3 in order to address each memory cell individually. The TAS MTJ-based MRAM cell 1 also comprises a word current line 4, shown above and perpendicular to the connecting current line 7 in the example of Fig. 3. Other configurations of the word current line 4 are however possible. For example the word current line 4 can be placed parallel with the connecting current line 7 and/or on the side of or below the junction 2.

[0031] An exploded view on the exemplary junction 2 is shown in figure 4. The junction 2 contains a storage layer 21 preferably comprising a ferromagnetic storage layer 21 a and an antiferromagnetic storage layer 21 b. The ferromagnetic storage layer 21 a has a thickness typically of the order of 1 to 10 nm and is made of a material having a planar magnetization, typically selected from the group Permalloy ($Ni_{80}Fe_{20}$), $Co_{90}Fe_{10}$ or other alloys containing Fe, Co or Ni. The ferromagnetic storage layer 21 a is exchange-coupled by the antiferromagnetic storage layer 21 b made of a manganese-based alloy, for example, of IrMn or FeMn. The antiferromagnetic storage layer 21 b has a blocking temperature T_{BS} sufficiently high to ensure that at a low temperature threshold below T_{BS}, for example, at standby temperature, i.e., in the absence of heating, magnetization of the ferromagnetic storage layer 21 a is sufficiently pinned to be able to preserve its magnetization over a period of several years but not so high as to make it necessary to heat the junction excessively during every the writing process that could yield to material degradation and high power consumption. Here, a T_{BS} in the range of, for example, 120 to 220°C is suitable.

[0032] The junction 2 also contains a reference layer 23 preferably comprising a first ferromagnetic reference layer 23a and a second ferromagnetic reference layer 23c, both formed of a Fe, Co or Ni based alloy. The two ferromagnetic reference layers 23a, 23c are antiferromagnetically coupled by inserting between them a non-ferromagnetic reference layer 23b made, for example, of ruthenium. An antiferromagnetic reference layer 24, preferably formed of a Mn based alloy such as PtMn or NiMn and characterized by a blocking temperature T_{BR} higher than T_{BS}, is provided below the second ferromagnetic reference layer 23c. The antiferromagnetic reference layer 24 orients the magnetic moment of the first ferromagnetic reference layer 23a, and a pinning field is generated that fixes the magnetic moment of the second ferromagnetic reference layer 23c. The reference layer structure described above is well known in the state of the art under the name of synthetic antiferromagnet pinned layer. Other configurations of the storage layer 23 are also possible. For example, the reference layer 23 can comprise a single ferromagnetic reference layer pinned by the antiferromagnetic reference layer 24 described above.

[0033] An insulating layer 22 playing the role of a tunnel barrier and preferably made of a material selected from the group comprising Al_2O_3 and MgO is inserted between the storage layer 21 and the reference layer 23. The tunneling resistance of a junction depends exponentially on the insulating layer thickness and is measured by the resistance-area product (RA) of the junction. The RA must sufficiently small in order to flow the junction current 31 through the junction, sufficiently high to raise the temperature of the antiferromagnetic storage layer 21 b above its blocking temperature T_{BS}. In order to force a current density in the range of 10^5A/cm^2 to 10^7A/cm^2, typically required to raise the temperature of the junction up to 100°C, the RA value should be of the order of 1 to 500 $\Omega.\mu m^2$.

[0034] In another embodiment, the junction 2, at least one thermal barrier layer (not shown) made typically of BiTe or GeSbTe and having a very low thermal conductivity can be added at the top and at the bottom of the junction 2. The purpose of these additional layers is to increase the heating efficiency of the junction current 31 flowing through the junction while limiting the diffusion of the heat towards the electrode (not shown) ensuring the electrical connection between the junction 2 and the connecting current line 7. Here, the thermal barrier itself is electrically connected to the electrode directly or via a conductive layer, for example made of TiN or TiWN.

[0035] During the thermally assisted writing process, the junction current pulse 31 having a magnitude comprised between 10^5 A/cm^2 and 10^7 A/cm^2 and lasting several nanoseconds is sent through a connecting current line 7 and the junction 2 (with transistor ON), rising the temperature of the junction to a high temperature threshold of about 120 to 220°C, lying between T_{BS} and T_{BR} where the magnetic coupling between the ferromagnetic storage layer 21 a and antiferromagnetic storage layer 21 b disappears and the magnetization of the ferromagnetic storage layer 21 a, being no more pinned, can be freely adjusted. The junction 2 is then cooled while a moderate word magnetic field 41 is applied by flowing a current in the word current line 4, allowing for the aligning of the magnetization of the ferromagnetic storage layer 21 a in a direction according to the magnetic field 41 orientation, essentially parallel or antiparallel with the magnetization orientation of the reference layer 23. The magnetic tunnel junction 2 is then cooled down at a low temperature threshold below the blocking temperature T_{BS} of the antiferromagnetic storage layer 21 b, where the magnetization of the ferromagnetic storage layer 21 a becomes pinned in its reversed direction, or written state.

[0036] According to the present invention, the magnetic tunnel junction 2 has an anisotropic shape, such as an elliptical shape, and the ferromagnetic storage layer 21 a has a magnetocrystalline anisotropy that is oriented essentially perpendicular to the long axis of the anisotropic shape of the junction 2. In other words, in the TAS MTJ-based MRAM cell 1 of the invention, the magnetization of the ferromagnetic storage layer 21 a is oriented in a direction that is essentially perpendicular with the long axis, or easy axis, of the anisotropic shape of the junction 2 at a high temperature threshold, when the magnetization of the ferromagnetic storage layer 21 a can be freely adjusted.

[0037] An advantage of using such a junction geometry and magnetocrystalline orientation can be seen from the variation in the writing (or coercive) field, H_R, of the ferromagnetic storage layer 21a with the junction aspect ratio. Figure 5 compares the variation of the word magnetic field 41, or writing field H_R, with the junction aspect ratio AR for a conventional memory cell, where the ferromagnetic storage layer 21 a has a magnetocrystalline anisotropy axis parallel to the long axis of the ellipse (filled circles), and for the memory cell 1 of the invention, where the ferromagnetic storage layer 21 a has a magnetocrystalline anisotropy axis perpendicular to the long axis of the ellipse (open circles). Here, the variation of the writing field H_R has been calculated for the junction anisotropic shapes having aspect ratios AR comprised between 1.0 and 1.1. The calculations were performed by means of micromagnetic simulations assuming standard material parameters corresponding to the ferromagnetic storage layer 21 a employed in a usual TAS MTJ-based MRAM cell 1 and assuming that the writing field H_R is applied parallel to the magnetocrystalline anisotropy axis. The calculations also assumed that the writing field H_R is not influenced by the dispersion in ellipticity and is essentially given by the magnetocrystalline anisotropy value corresponding, for example, to the writing field of a circular junction (AR=1.0).

[0038] In the present invention, the shape of the junction 2 is not limited to an elliptical shape but can have any shape that is anisotropic, such as a rectangle, crescent, semi-ellipse, diamond, etc., where the magnetocrystalline anisotropy axis is essentially perpendicular to the long axis of the anisotropic shape of the junction 2.

[0039] As can be seen in figure 5, the writing field H_R increases approximately linearly with the memory cell aspect ratio AR, for a magnetocrystalline anisotropy axis of the ferromagnetic storage layer 21a that is essentially parallel to the long axis of the ellipse. In this case, a variation in the memory cell aspect ratio AR due to the manufacturing process will result in an overall increase in the writing field H_R and a larger power consumption of the magnetic memory device. Conversely, in the case of a magnetocrystalline anisotropy being essentially perpendicular to the long axis of the ellipse, the writing field H_R decreases approximately linearly with the aspect ratio AR, and a variation in the memory cell aspect ratio AR will tend to diminish the overall writing field H_R and power consumption of the magnetic memory cell 1.

[0040] In an embodiment of the present invention, the junction 2 of the memory cell is characterized by an aspect ratio AR equal or above a value of 1.0, corresponding to a circular (or square, etc.) junction 2, but preferably comprised between 1.0 and 1.5, and a magnetocrystalline anisotropy axis of the ferromagnetic storage layer 21 a perpendicular to the long axis of the ellipse.

[0041] A magnetic memory device (not represented) can be formed by assembling a matrix comprising a plurality of TAS MTJ-based MRAM cells 1 of the invention, where each junction 2 of each memory cell 1 is connected on the side of the storage layer 21, or ferromagnetic storage layer 21 a, to the connecting current line 7, and on the opposite side to the control current line 6, placed perpendicular with the connecting current line 7. When one of the memory cells 1 is to be written, a current pulse is sent in one or several control lines 6 in order to put at least one of the transistors 3 of the corresponding control lines 6 in mode ON, and a junction current pulse 31 is sent to each connecting lines 7 corresponding to the memory cells 1 to be written, i.e., the memory cells 1 placed at the intersection of the active connecting current lines 7 and active control lines 6.

[0042] Using today's lithographic fabrication processes a maximal variation, Δ_e, in the shape anisotropy of the junction 2 of about ±5% can be typically obtained. This corresponds, for example, to an aspect ratio AR of the junction 2 varying from 1.0 to 1.1 with an average aspect ratio of 1.05, for the memory cells 1 of the magnetic memory device. In the exemplary calculations of Fig. 5, an anisotropic shape with an aspect ratio AR of 1.05 corresponds to a writing field H_R of about 25 Oe, for the TAS MTJ-based MRAM cell 1 of the invention. This represents a decrease of about 30% in the writing field value compared to the one calculated for a junction 2 with an aspect ratio AR of 1.

[0043] In a preferred embodiment, the junction 2 of the memory cell 1 has an aspect ratio AR comprised within the maximum shape anisotropy variations allowed by the fabrication process used for the memory cell fabrication, and has a magnetocrystalline anisotropy axis of the ferromagnetic storage layer 21 a perpendicular to the long axis of the junction anisotropic shape. For example, the junction 2 of the memory cell 1 has an aspect ratio AR comprised between 1.0 and 1.1.

[0044] Continuous improvements in the fabrication processes may equally allow for smaller variations in the aspect ratio AR of the junctions 2 within the memory device. For example, using such advanced fabrication technologies, the junction 2 of the memory cell 1 could be characterized by an aspect ratio AR comprised between 1.0 and 1.05, or even smaller.

[0045] Fig. 6 compares schematically the top view of a conventional junction with a field induced magnetic switching (FIMS) architecture having an aspect ratio AR of 1.5, with two junctions 2 of the TAS MTJ-based MRAM cell 1 of the present invention having aspect ratios AR of 1.0 and 1.05 respectively.

[0046] In another embodiment of the invention, the variation of the junction aspect ratio AR is minimized by using an appropriate fabrication process and/or by a careful control of the fabrication process and/or by selecting fabricated memory cells 1 having the least variation possible in their aspect ratio AR. Here, the magnetic memory device containing such junctions 2 with an aspect ratio AR of about 1.0 or any other value, can be fabricated with no or a very small dispersion in the aspect ratio AR. Such memory device can have minimal variations of the writing field H_R due to the combined effect of the small or inexistent dispersion, in the junction aspect ratios AR, and in the magnetocrystalline anisotropy axis of the ferromagnetic storage layer 21 a being essentially perpendicular to the long axis of the anisotropic shape of the junctions 2.

[0047] In yet another embodiment, the junctions 2 of the memory device have a magnetocrystalline anisotropy axis of the ferromagnetic storage layer 21 a essentially parallel to the long axis of the junction anisotropic shape, the latter having a very small or no dispersion of the aspect ratio AR.

[0048] The fact that the magnetocrystalline anisotropy axis of the ferromagnetic storage layer 21 a is perpendicular to the long axis of the anisotropic shape of the junction 2, gives rise to a competition between the magnetocrystalline anisotropy and shape anisotropy terms of the barrier energy, E_b. For example, in the absence of an external applied magnetic field, the magnetic moments of the ferromagnetic storage layer 21 a may be tilted with respect to the magnetic moments of the reference layer 23. This tilt can increase with increasing aspect ratios AR, translating in an important dispersion in the resistance value during the reading operation, and resulting in a loss in the read margin that corresponds to the difference between low and high resistance states.

[0049] With the TAS MTJ-based MRAM cell 1 of the present invention, however, the writing sequence comprises a last cooling step of the junction 2, performed under the word magnetic field 41, corresponding to the writing field H_R. This word magnetic field 41 "freezes" the magnetic state of the ferromagnetic storage layer 21 a resulting in a much reduced tilt of the magnetic moments of the ferromagnetic storage layer 21a with respect to the reference layer 23, yielding to a much lesser influence in the read margin. For example, a loss of less than 20% for the read margin is expected in the case of the junction 2 with a shape anisotropy variation of 10%.

[0050] It is understood that the present invention is not limited to the exemplary embodiments described above and other examples of implementations are also possible within the scope of the patent claims.

[0051] For example, other configurations of the TAS MTJ-based MRAM cell 1 can possibly be used in the context of the present invention provided the junction 2 is fabricated with an isotropic (circular, square, etc.) or anisotropic (elliptical, rectangular, etc.) geometry and has a magnetocrystalline anisotropy axis of the ferromagnetic storage layer 21 a, essentially parallel to the long axis of the anisotropic shape of the junction 2. An example of another TAS MTJ-based MRAM cell 1 configuration is the memory cell described in unpublished patent application EP07291520 by the present applicant, where the junction 2 comprises a writing layer added on top of the storage layer 21. Another example is the junction described in patent application US2005002228 of a general thermally assisted MRAM architecture, where the writing process is ensured by the combination of one magnetic field and a local heating, and the storage layer is exchanged biased with an antiferromagnetic layer.

Reference Numbers

[0052]

1	memory cell
2	magnetic tunnel junction
21	storage layer
21a	ferromagnetic storage layer
21b	antiferromagnetic storage layer
22	insulating layer
23	reference layer

23a	first ferromagnetic reference layer
23b	non-ferromagnetic reference layer
23c	second ferromagnetic reference layer
24	antiferromagnetic reference layer
3	select transistor
31	junction current pulse
4	word current line
41	word magnetic field
5	bit current line
51	bit magnetic field
6	control current line
7	connecting current line

Reference Symbols

[0053]

AR	aspect ratio of the memory cell
AR-1	ellipticity of the memory cell
E_b	barrier energy
H_R	writing (coercive) field of the ferromagnetic storage layer
L	width of the junction
M_s	saturation magnetization of the memory cell
RA	resistance-area product of the insulating layer
t	thickness of the storage layer
T_{BS}	blocking temperature of the antiferromagnetic storage layer
T_{BR}	blocking temperature of the antiferromagnetic reference layer
Δ_e	maximal variation in the junction anisotropy

Claims

1. A magnetic tunnel junction (MTJ) -based magnetic random access memory (MRAM) cell (1) with a thermally assisted switching (TAS) writing procedure comprising a magnetic tunnel junction (2) formed from a ferromagnetic storage layer (21 a) having a magnetization that is adjustable above a high temperature threshold, a reference layer (23) having a fixed magnetization, and an insulating layer (22) being disposed between the storage and reference layers (21 a, 23);
characterized in that
the junction (2) has an anisotropic shape, and wherein
the ferromagnetic storage layer (21 a) has a magnetocrystalline anisotropy being oriented essentially perpendicular to the long axis of the anisotropic shape of the junction (2).

2. The TAS MTJ-based MRAM cell (1) according to claim 1, wherein
the anisotropic shape of the magnetic tunnel junction is an elliptical or a rectangle or a crescent or a semi-ellipse or a diamond shape.

3. The TAS MTJ-based MRAM cell (1) according to the claims from 1 or 2, wherein the junction (2) has an anisotropic shape with an aspect ratio (AR) comprised between 1.0 and 1.5.

4. The TAS MTJ-based MRAM cell (1) according to the claims from 1 or 2, wherein
the junction (2) has an anisotropic shape with an aspect ratio (AR) comprised between 1.0 and 1.1 or comprised between 1.0 and 1.05.

5. The TAS MTJ-based MRAM cell (1) according to the claims from 1 or 2, wherein
the junction (2) has an anisotropic shape with an aspect ratio (AR) of 1.05.

6. The TAS MTJ-based MRAM cell (1) according to any of the claims from 1 to 5, wherein
said magnetic tunnel junction (2) further comprises an antiferromagnetic storage layer (21 b) exchange-coupling the ferromagnetic storage layer (21 a), pinning its magnetization below a low temperature threshold and freeing its magnetization above the high temperature threshold.

7. The TAS MTJ-based MRAM cell (1) according to any of the claims from 1 to 6, wherein
said magnetic tunnel junction (2) further comprises an antiferromagnetic reference layer (24) and wherein
said reference layer (23) comprises a single ferromagnetic reference layer being pinned by the antiferromagnetic reference layer (24).

8. The TAS MTJ-based MRAM cell (1) according to any of the claims from 1 to 6, wherein
said magnetic tunnel junction (2) further comprises an antiferromagnetic reference layer (24) and wherein
said reference layer (23) comprises a first ferromagnetic reference layer (23a) and a second ferromagnetic reference layer (23c) being antiferromagnetically coupled by a non-ferromagnetic reference layer (23b), at least one of the first and second ferromagnetic reference layers (23a, 23c) being pinned by the antiferromagnetic reference layer (24).

9. A magnetic memory device formed from an array comprising a plurality of TAS-MRAM cells (1) **characterized by** any of the claims from 1 to 8

10. A method of writing data in a thermally assisted switching (TAS), magnetic tunnel junction (MTJ) -based magnetic random access memory (MRAM) cell (1), the TAS MTJ-based MRAM cell (1) comprising a magnetic tunnel junction (2) formed from a ferromagnetic storage layer (21a) having a magnetization that is adjustable above a high temperature threshold, a reference layer (23) having a fixed magnetization, and an insulating layer (22) being disposed between the storage and reference layers (21 a, 23); the cell (1) further comprising a select transistor (3) being coupled with the magnetic tunnel junction (2) and controllable via a word line (6), a connecting current line (7) electrically connected to the magnetic tunnel junction (2), and a word current line (4); wherein the junction (2) has an anisotropic shape, and the ferromagnetic storage layer (21 a) has a magnetocrystalline anisotropy being oriented essentially perpendicular to the long axis of the anisotropic shape of the junction (2); the method comprising the steps of:

heating the magnetic tunnel junction (2) until it has reached a high temperature threshold;
aligning the magnetization of the ferromagnetic storage layer (21a) in a direction essentially parallel or antiparallel with the magnetization orientation of the reference layer (23);
cooling down the magnetic tunnel junction (2) to a low temperature threshold at which the magnetization of the ferromagnetic storage layer (21 a) is pinned.

11. The method according to claim 10, wherein
said heating of the magnetic tunnel junction (2) includes passing a junction current pulse (31) through the magnetic tunnel junction (2) via the connecting current line (7) when the transistor (3) is in an open mode.

12. The method according to claims 10 or 11, wherein
said aligning the magnetization of the ferromagnetic storage layer (21a) is performed by a word magnetic field (41) generated by passing a current in the word current line (4).

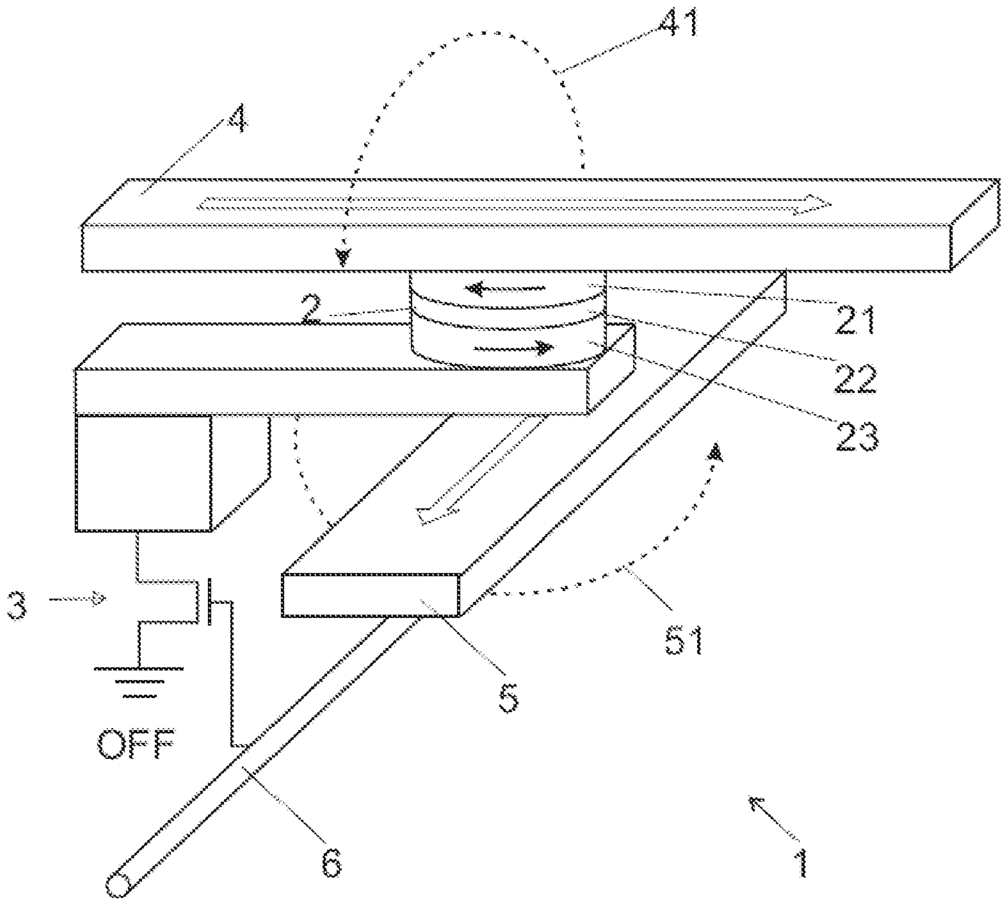

Fig. 1

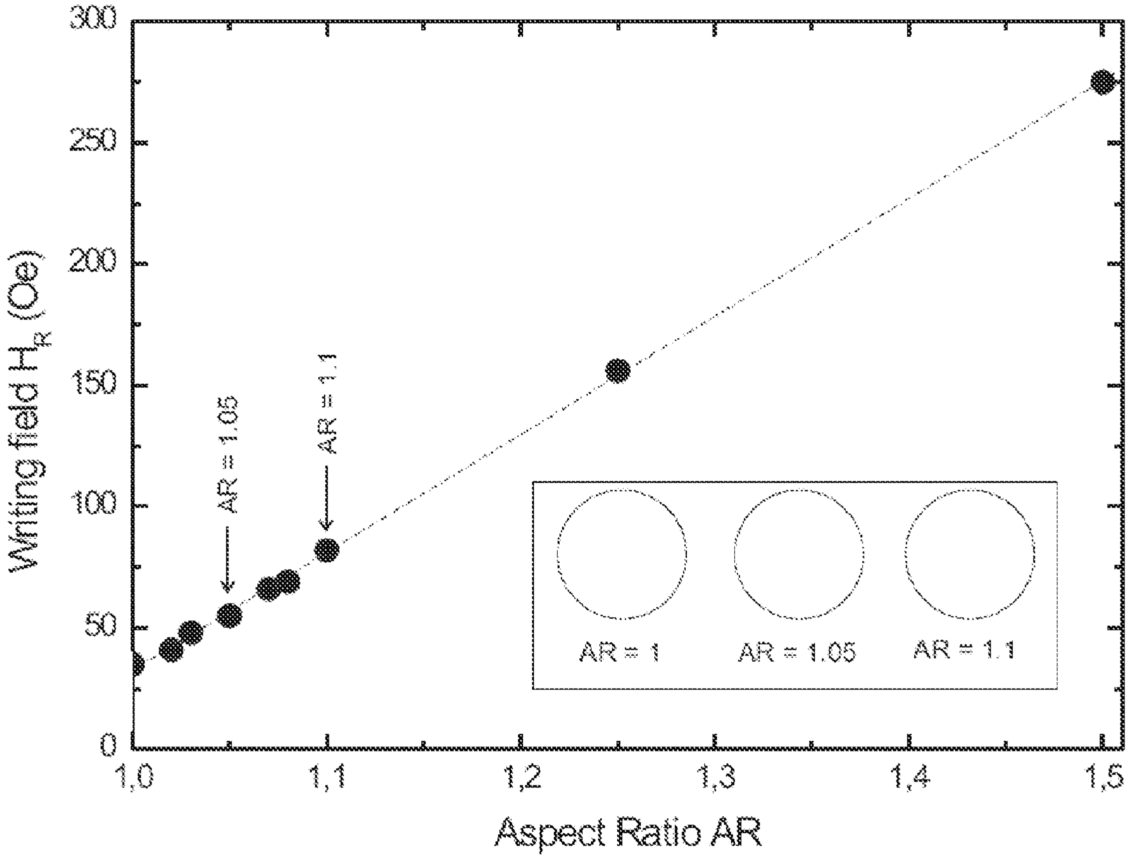
300
250
200
150
100
50
0
Writing field H_R (Oe)
1,0
1,1
1,2
1,3
1,4
1,5
Aspect Ratio AR
AR = 1.05
AR = 1.1
AR = 1
AR = 1.05
AR = 1.1

Fig. 2

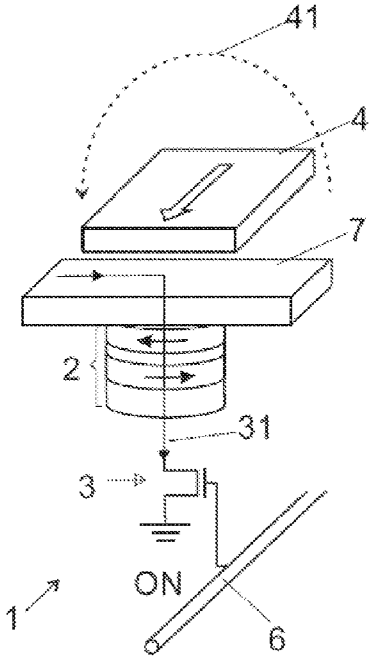

Fig. 3

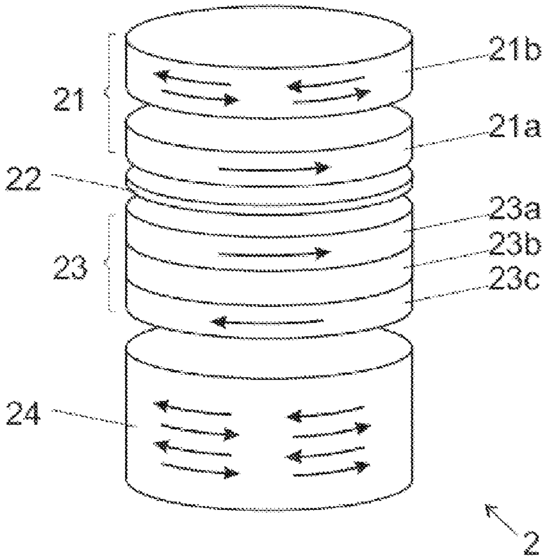

Fig. 4

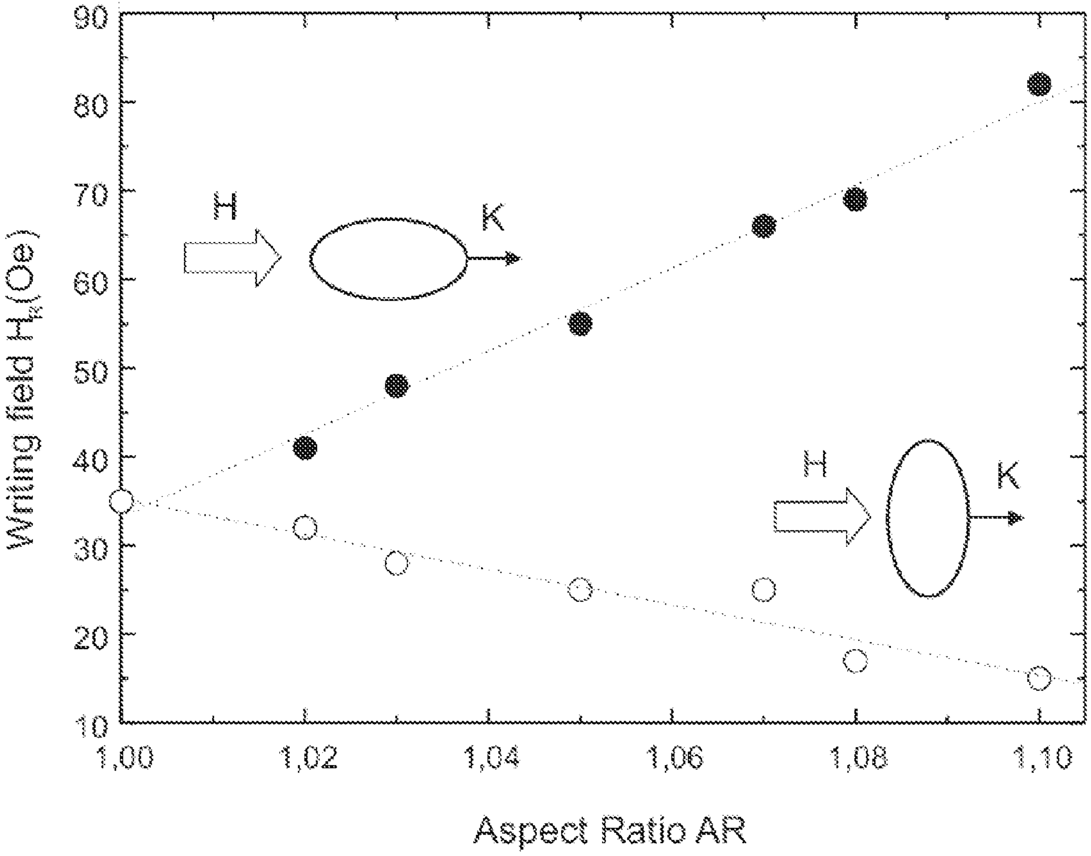
90
80
70
60
50
40
30
20
10
Writing field H_R(Oe)
1,00
1,02
1,04
1,06
1,08
1,10
Aspect Ratio AR
H
K
H
K

Fig. 5

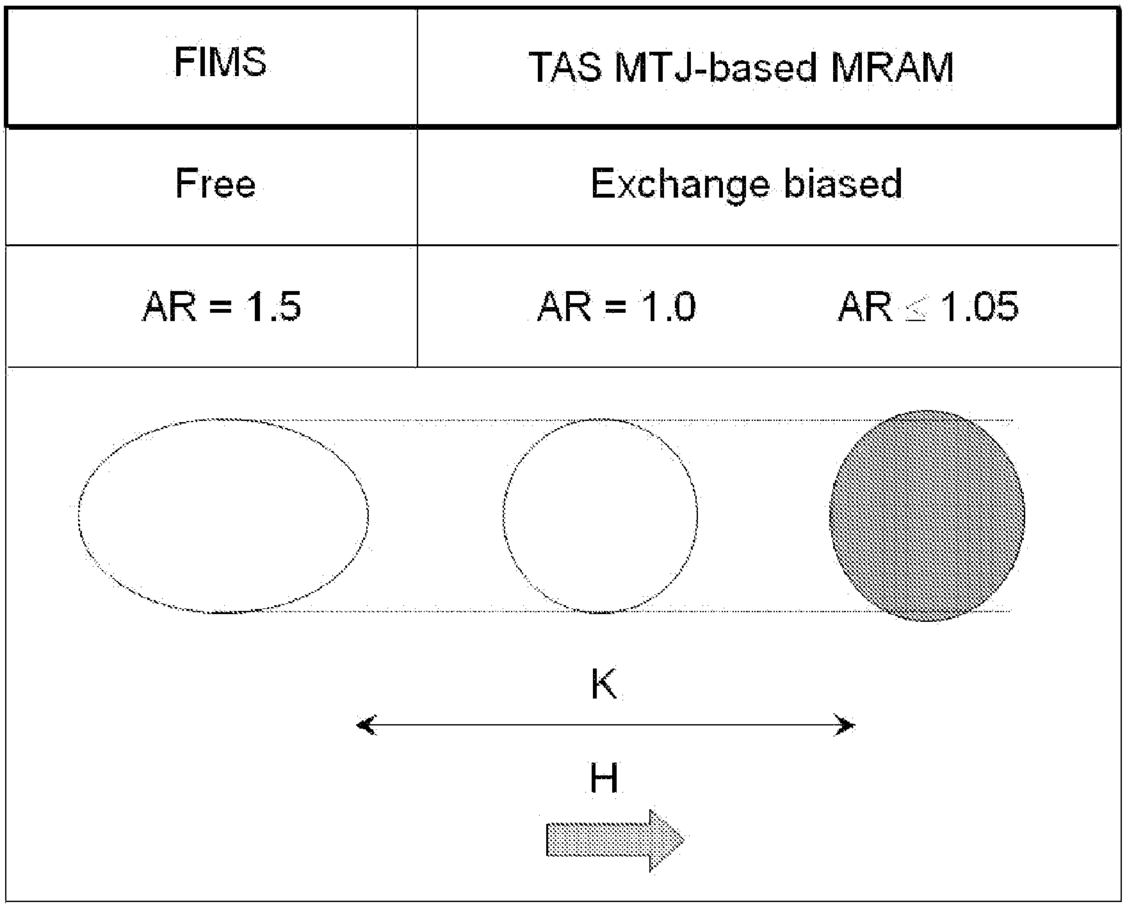
FIMS
TAS MTJ-based MRAM
Free
Exchange biased
AR = 1.5
AR = 1.0
AR ≤ 1.05
K
H

Fig. 6

Europäisches Patentamt
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EUROPEAN SEARCH REPORT

Application Number
EP 09 16 0167

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	PURNAMA ET AL: "Micromagnetic simulation of thermally assisted magnetization reversal in magnetic nanodots with perpendicular anisotropy" JOURNAL OF MAGNETISM AND MAGNETIC MATERIALS, ELSEVIER SCIENCE PUBLISHERS, AMSTERDAM, NL, vol. 310, no. 2, 16 March 2007 (2007-03-16), pages 2683-2685, XP022048680 ISSN: 0304-8853 * page 2685, paragraph 2 * -----	1-12	INV. G11C11/155
Y	WO 2008/040561 A (CROCUS TECHNOLOGY S A [FR]; NOZIERES JEAN-PIERRE [FR]; JAVERLIAC VIRGI) 10 April 2008 (2008-04-10) * abstract * & US 7 518 897 B2 (NOZIERES JEAN-PIERRE [FR] ET AL) 14 April 2009 (2009-04-14) * column 7, line 48 - column 8, line 62; figures 3,7,8 * -----	1-12	TECHNICAL FIELDS SEARCHED (IPC)
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	21 August 2009	Wolff, Norbert

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
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& : member of the same patent family, corresponding document

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EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

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21-08-2009

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